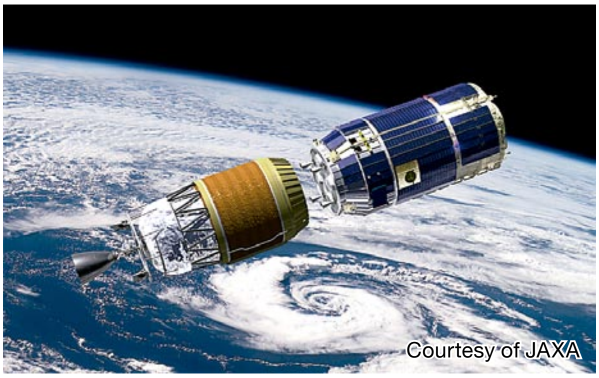

Overview of the HTV Mechanical Environmental Tests Using the Structural Test Model

HIDEFUMI KAWANO*1 MAKOTO KAMATA*1
TOSHIO NAKAMURA*2

As a cargo transportation system for the International Space Station, the H-II Transfer Vehicle (HTV) is a rocket-launched spacecraft of unprecedented size. Therefore, it requires more advanced and a larger range of verification testing of the acoustic and separation shock load at launch compared with the development of a conventional satellite. The development of the HTV has been greatly advanced through the completion of mechanical environmental tests (vibro-acoustic test and separation shock test). The knowledge and lessons obtained through the mechanical environmental tests will be valuable because they can be helpful for the development of the successor spacecraft to the HTV.

1. Introduction

The H-II Transfer Vehicle (HTV) has been developed by the Japan Aerospace Exploration Agency (JAXA) with Mitsubishi Heavy Industries, Ltd. (MHI) acting as the overall system integrator as well as being responsible for the structural and mechanical system design. The HTV will be launched by the H-IIB launch vehicle, and the evaluation of its ability to withstand launch-time acoustic and separation shock is an important factor in the structural and mechanical system design. In this paper, MHI outlines the mechanical environmental tests (vibroacoustic and separation shock tests) conducted using the structural test model (STM) that was built for evaluating the HTV system, and describes the knowledge obtained and lessons learned from the test results.

2. Outline of the HTV STM

2.1 HTV outline

The HTV consists of the four modules shown in **Fig. 1**. The pressurized and unpressurized logistics carriers are designed to carry the cargo (payload). The unpressurized logistics carrier (UPLC) has a large opening to mount an exposed pallet, which is designed to carry and expose payloads to space.[1] The avionics and propulsion modules are bus sections designed to provide inter-orbit transport functions.

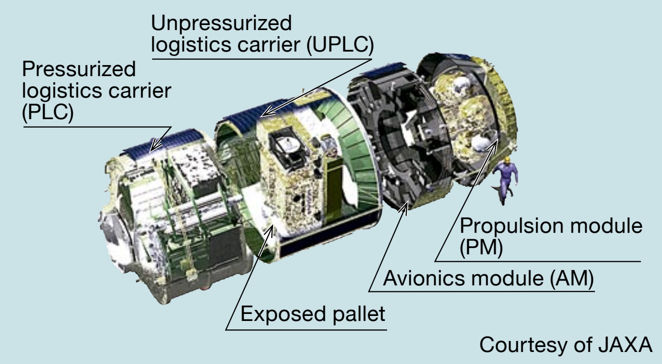

Fig. 1 HTV overview

2.2 Test evaluation scope

The development of the pressurized logistics carrier (PLC), which will be positioned on the top of the HTV in the launch configuration, is currently underway following the Japanese Experimental Module (JEM: KIBO). Therefore, the development process of the PLC is different from that of the other modules.

The complete STM, excluding the PLC, was created to evaluate the UPLC, avionics module, and propulsion module together. This paper describes the contents of that evaluation along with the mechanical environmental conditions (acoustic and separation shock) that will be generated during the launch of the HTV.

3. Structural test model

The configuration of the STM is shown in **Fig. 2**. As described above, since the PLC is being separately evaluated, a dummy PLC model was mounted on the test model to simulate the mechanical interfaces with the UPLC. The primary structure and internal onboard structures in the UPLC, the avionics module, and the propulsion module form an equivalent test model for the actual vehicle that will be launched. The onboard components in the test model are dummies, with the same weight and center of gravity as in the flight model, because the main purpose of these STM tests is not to confirm the structural properties of each component. These have been confirmed individually at the component or subsystem level. The STM tests are planned to confirm the validity of the acoustic/random

---

*1 Nagoya Guidance & Propulsion Systems Works
*2 Nagasaki Research & Development Center, Technical Headquarters

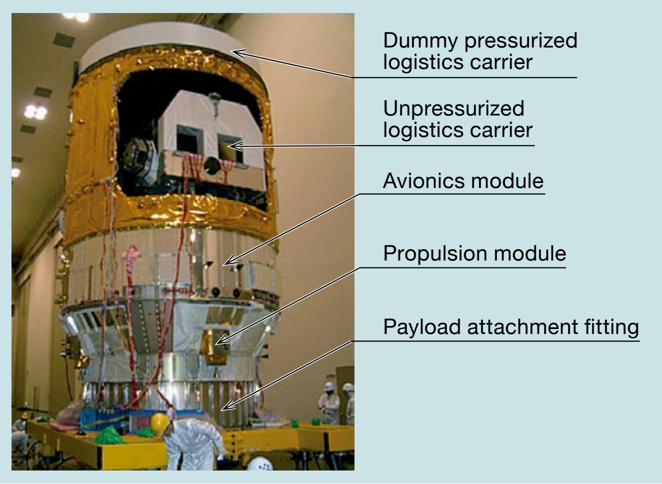

Fig. 2 HTV structural test model

vibration environmental conditions and shock environmental conditions that have been applied to the design and development of each section and component.

4. Vibroacoustic tests

4.1 Purpose of the vibroacoustic tests

The purpose of the STM vibro-acoustic test is to measure the random vibration environment generated at each section of the HTV and component installation sections by the acoustic environment at launch in order to confirm the validity of the random vibration conditions (specification value) applied to the development of each component. If the random vibration conditions measured in this test deviate from the specifications used during the component development, some additional evaluation will be required.

4.2 Test configuration

The configuration of the STM vibroacoustic tests is shown in **Fig. 3**. The tests were conducted in the 1600 m^3 vibroacoustic test facility in the Spacecraft Integration and Test Building (SITE) at the JAXA Tsukuba Space Center. In order to simulate the interface at the lower end of the HTV (bottom of the propulsion module), the payload attachment fitting (PAF) structure was mounted on a dedicated dolly. Six control microphones were located around the HTV STM. Measurements from approximately 600 acceleration sensors were taken during the test evaluation.

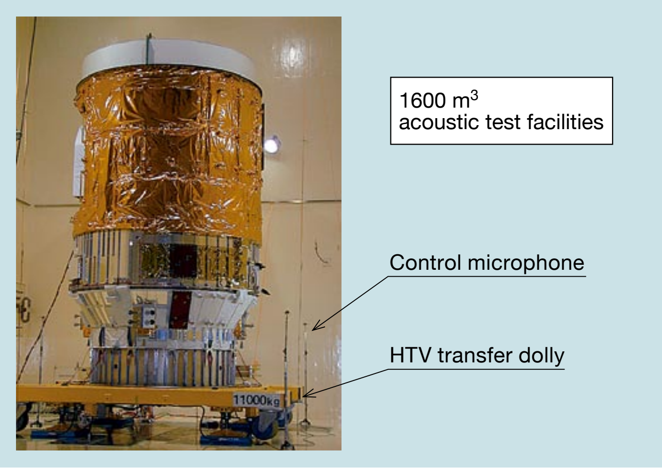

Fig. 3 STM vibroacoustic test configuration

4.3 Test conditions

The acoustic loading level is shown in **Fig. 4**. This was the same as the qualification test level, 3 dB greater than the maximum expected flight level (MEFL). The level labeled H-IIA I/F in Fig. 4 was previously used in HTV development. However, before conducting these mechanical environment tests, the acoustic environmental conditions for the launch of the H-IIB vehicle were revised to incorporate the fill effect inside the rocket fairing. The revised level is labeled H-IIB I/F in Fig. 4.

The measurements were conducted at both loading levels during the tests. However, the practical evaluation was based on the results measured at the H-IIB I/F level because the revised level was adopted after consultation with an H-IIB launch vehicle team.

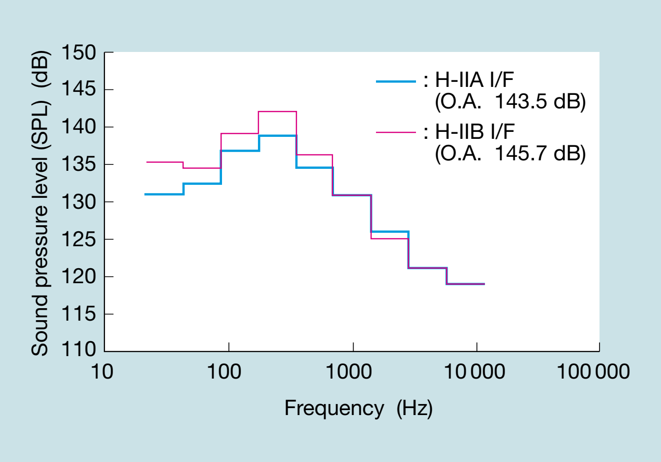

Fig. 4 Acoustic loading level

4.4 Test results

The outline of the test results is as follows.

Success and failure of the test

- Although there were measurements missing from some acceleration sensors, sufficient test data to achieve the test objectives was obtained using data from backup measurement points.

Measurement results

- It was confirmed that the random vibration acceleration responses averaged over each section were within their own specified ranges. However, some isolated resonance peaks were observed at some measurement points. Most of these were in a frequency range of 200–300 Hz, and were on the outer edges of the primary structure.

- The UPLC has a large opening that was described in section 2.1. Past estimates of the acoustic environment inside the HTV assumed an outside level and did not take into account the sound transmission loss due to the actual vehicle structure. Our results showed that the measured acoustic pressure inside the STM was several dB less than that outside.

4.5 Discussion

The following observations were due to the fact that the random vibration level of external components was more prone to deviation from the specifications than that of internal components.

(1) The acoustic pressure loading level was highest as an external force in the 200–300-Hz frequency range. In addition, analysis of the results showed that a petal-shaped vibration mode in the corresponding frequency range on the primary structure (**Fig. 5**).

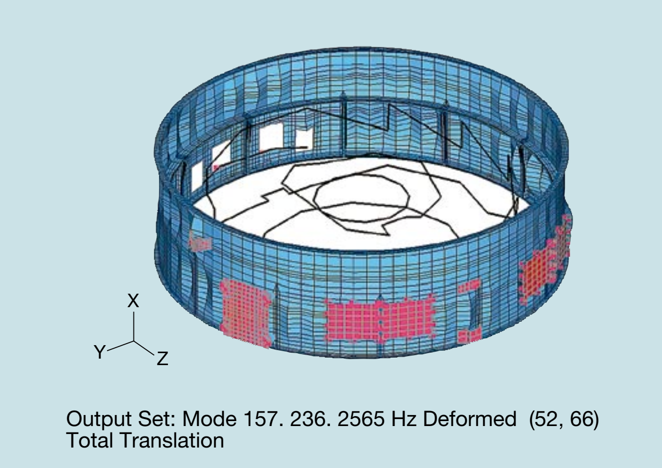

Fig. 5 Petal-shaped vibration mode

(2) The design of the primary structure was critical in terms of strength evaluation since weight minimization was one of the primary objectives.[1] Therefore, the external primary structure was more likely to vibrate than the internal structure, which had a relatively high stiffness.

However, there were no critical deviations from the specifications that warranted drastic changes to the primary structure. Some proposals were made included strengthening some components and modifying installation brackets. In other words, the specifications that had been applied to each component from the beginning of the HTV development were generally appropriate.

4.6 Evaluation of RRS

The power spectrum density (PSD) was normally used to identify the existence of anomalies. Besides this, the random response spectrum (RRS)[2] was used to compare them when measuring the random vibration acceleration against the specified values. In other words, if the RRS of the measurement value was within specifications, we determined that no problem existed, even if there were some deviations outside the PSD-specified values. **Figure 6** shows an evaluation example.

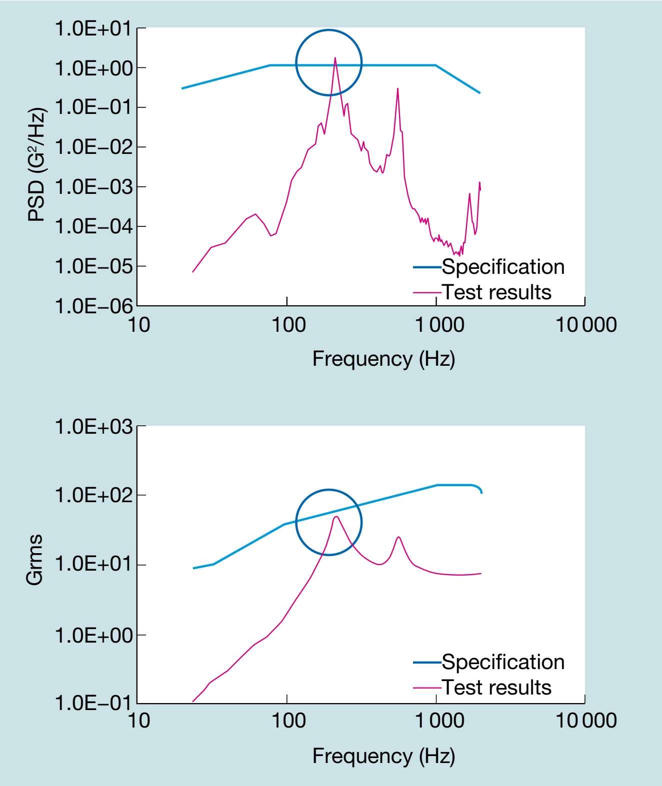

Fig. 6 Example of the RSS evaluation of random vibration response
Although the test results were outside the value specified by the PSD, they were inside the RSS specifications. No problems were identified.

5. Separation shock tests

5.1 Purpose of the separation shock tests

Separation occurs when the HTV and the H-IIB launch vehicle move apart in orbit after activating separation nuts. The objectives of the STM separation shock tests are to measure the level of acceleration shock transmitted to the vicinity of the separation shock source as well as to each section of the HTV, and to confirm that the measured level is within the shock acceleration environmental specifications in the development of each component. Thus, if the measured shock acceleration environment in this test deviates from the specifications used in the HTV development, some additional evaluation will be required.

5.2 Test configuration

The STM test configuration for the separation shock test is shown in **Fig. 7**. The test was conducted in the SITE assembly preparation area at the JAXA Tsukuba Space Center. The STM was suspended approximately 50 mm above the floor by slings attached to the dummy PLC, which was mounted on the upper end of the STM. The separation nuts were activated, and the shock acceleration for the separation section of the HTV/H-IIB launch vehicle was measured.

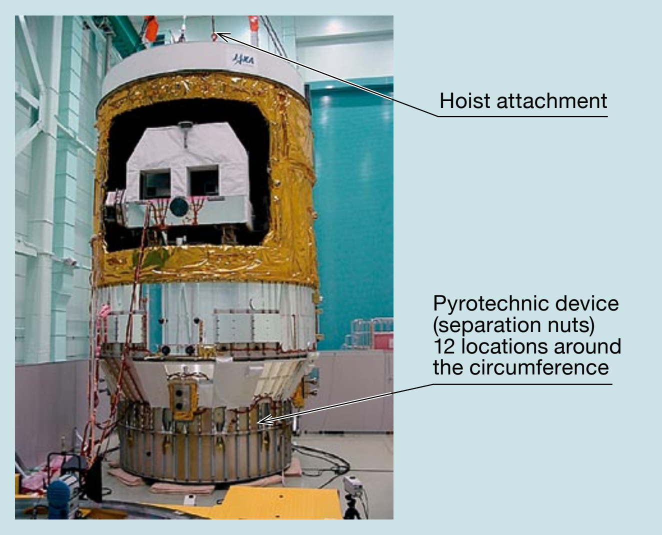

Fig. 7 STM shock test configuration

Measurements from approximately 330 acceleration sensors were used in the tests. Approximately 300 of these were in the same locations as the measurement points for the vibroacoustic tests described above. The additional sensors were attached in the vicinity of the shock source.

5.3 Test conditions

The separation section between the HTV and the H-IIB launch vehicle is connected with 12 separation nuts. In actual flight, these would fire in two groups of six separated by a sufficient time interval so that there is no chance of the shock overlapping from the first to the second ignitions.

During the tests, the first six nuts were activated, then the second six nuts were activated, and the separation section dropped to the floor. Since the second group of separation nuts was successfully affected by the shock of the first operation, the load bearing properties at the separation nuts were confirmed.

Two rounds of separation shock testing (i.e., triggering four sets of six separation nuts) were conducted to confirm the repeatability.

5.4 Test results

The overview of the test results is as follows.

Success and failure of the tests

Like the vibroacoustic tests described above, there were measurements missing from some acceleration sensors, but we were able to obtain sufficient test data to meet the test objectives using data from backup measurement points.

Measurement results

- All the separation nuts functioned normally. High-speed videos of the separation process showed no particular problems. Furthermore, the separation switch (a plunger sensor that confirms the separation) was activated normally.
- The shock acceleration at the HTV/H-IIB separation plane was within the environmental specifications overall.
- Some of the low-frequency data were outside the specified values for a small portion of the avionics system components. However, since the components involved had an adequate load-bearing margin in the low-frequency area, this was not considered to be a problem.
- The shock acceleration in the UPLC containing cargo was sufficiently attenuated to the level of not causing any problems, as expected.

5.5 Prediction versus tests

We predicted the shock acceleration transmitted from the HTV/H-IIB launch vehicle separation plane to the HTV internal structure based on attenuation with distance from the source and with structural interfaces obtained from NASA's documents,[3] the shock acceleration level applied to each component was specified based on this prediction. **Figure 8** compares the predictions and test results. The attenuation predictions were reasonably accurate.

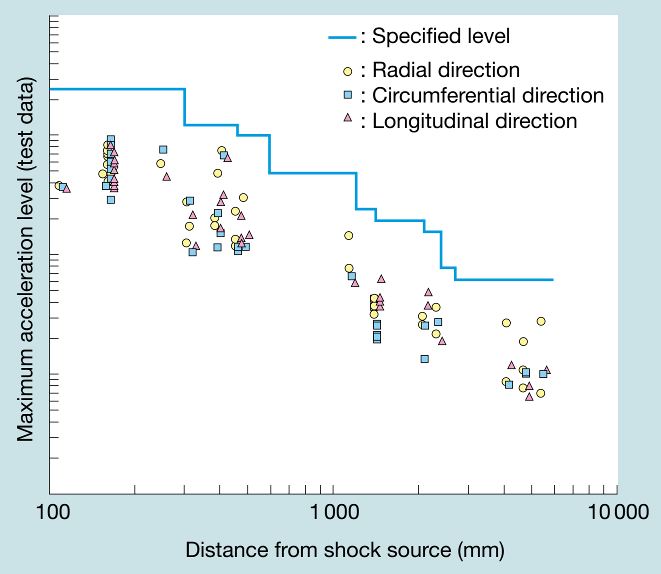

Fig. 8 Comparison of the shock acceleration predictions and test results

6. Conclusion

Using the two tests described above, we confirmed that the HTV system specifications were suitable for the mechanical environmental conditions (acoustic and separation shock) during the launch of the H-IIB vehicle. Unlike conventional spacecraft systems, these were large-scale tests due to the nature of the model. The success of these tests was largely attributable to the innovative ideas applied to the test plan.

In addition, we confirmed that the internal acoustic level of the UPLC tended to be several decibels lower than the outside level despite the large opening. These test results could lead to an improvement in the HTV availability. For example, it may be possible to specify less stringent environmental conditions for cargo transported in the UPLC.

The HTV development is now shifting to the fabrication and testing of the prototype flight model (PFM), which will be the first flight model of the HTV. Vibroacoustic testing is planned to verify the flight system components of the PFM. The knowledge and lessons obtained from the tests described in this paper are being used in the development of the PFM.

Furthermore, plans for a successor to the HTV are already being considered, and we believe that lessons learned in this research will be adaptable to future developments.

References

1. Kawano, H. et al., Design and Development for the Unpressurized Logistics Carrier Primary Structure of H-II Transfer Vehicle (HTV), The 47th Meeting for Structural Strength, The Japan Society for Aeronautical & Space Sciences (2005) p.123

2. Minesugi, K. et al., Decision of Random Vibration Environment for S-520 Observation Rocket, The 35th Meeting for Structural Strength, The Japan Society for Aeronautical & Space Sciences (1993) p.62

3. NASA, CONTRACT NASS-15208 Aerospace Systems Pyrotechnic Shock Data 1970


Hidefumi Kawano


Makoto Kamata


Toshio Nakamura